

DOCUMENT RESUME

ED 182 178

SE 029 971

AUTHOR Fisher, Nina Jo-Anne
TITLE Identification and Examination of Physics Concepts That Students Find Most Difficult.
SPONS AGENCY Educational Research Inst. of British Columbia, Vancouver.
REPORT NO ERIBC-79:40
PUB DATE 79
GRANT ERIBC-DG-263
NOTE 43p.; Contains light and broken type

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Complexity Level; *Educational Research; *Physics; Science Education; *Scientific Concepts; Secondary Education; Secondary School Science; *Teacher Response

ABSTRACT

The relative apparent difficulty of physics concepts at the grade 11 and 12 level was examined using a questionnaire survey addressed to all physics teachers within the province of British Columbia. The physics courses were described using 22 concepts to cover the Physics 11 course and 30 concepts to cover the Physics 12 course. Subjects were asked to rate each concept using a 5-point index of difficulty. The second part of the questionnaire involved the identification of sources of difficulty through selection from a prepared list giving fourteen possible reasons. An overall response rate of 65% was obtained. In Physics 11 the most difficult concepts appear to be "vectors in three-dimensions," "projectile motion," and "diffraction of light"; while in Physics 12 the most difficult concepts are "the center-of-mass reference frame," and "simple harmonic motion." In specifying sources of difficulty, 40% of the responses were related to the text materials. (Author)

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FIND MOST DIFFICULT

Nina Fisher



**Educational Research Institute
of
British Columbia**

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Nina Jo-Anne Fisher
October, 1979.

This project was completed with financial support
from the Educational Research Institute of British
Columbia through the Discretionary Grants Program.

ACKNOWLEDGEMENTS

I would like to thank Dr. Gaalen Erickson of the Faculty of Education, UBC, for his kind support and encouragement throughout this project. In addition, a special vote of thanks to the following physics teachers for participating in the pilot study of the questionnaire: H. Strechel, R. Wilson, H. Spence, D. Kujawa, W.S. Hunter, D. Swetnam, and R. Ayliffe. Naturally, I must also thank all the physics teachers who returned the questionnaire for without their response this project would not have been possible .

Financial support for the project was provided through a grant from the Educational Research Institute of B.C. Access to computer time was generously provided by the Faculty of Education, UBC.

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I. Introduction

Many students view the formal study of physics at the secondary level with a mixture of apprehension and dismay. This view is frequently shared by their peer group, their parents, and even their other teachers; the general consensus being that physics is much too difficult for the average person.

Yet, by the age of sixteen, the average person has accumulated a wealth of personal experience which is directly related to the concepts usually taught in an introductory physics course- concepts like time, distance, speed, acceleration, force, circular motion, etc. Seen from this viewpoint, physics could be perceived as one of the easier sciences because of its direct link to everyday experience.

However, physics appears far from easy for the majority of students. The results of the 1978 B.C. Science Assessment reveal that almost 40% of the students do not take any science courses at the senior secondary level and that "girls avoid taking physical science courses, especially physics"

Furthermore, enrollment figures available from the Ministry of Education show that during the decade from 1969 to 1979, there has been a 32% increase in enrollment in Grade 12. During this same period, enrollment increased by 106% in Biology 12 and 35% in Chemistry 12 but by only 10% in Physics 12.

The apparent difficulty of the physics course is cause for concern. Curriculum decisions in physics have traditionally been determined by the structural logic of the subject matter with scant attention to the characteristics of the student. However, some recent science education research has focused attention on the way students understand physical phenomena and the structures which the students develop in order to make sense of their physical world. (Driver and Easley, 1978) Though still in its infancy, this research suggests the existence of a stable set of intuitive beliefs held by many students. (For example, see Hobbs and Erickson, 1978; Erickson, 1979) Knowledge of these beliefs may illuminate the problem of why physics concepts cause such difficulty by providing insight into the possible confusion between the students' beliefs and the physics concepts. Such knowledge could therefore be useful in the selection and sequencing of physics concepts within the curriculum.

Before detailed studies of individual physics concepts can be undertaken, some baseline information would be useful. First, it would be desirable to order physics concepts according to apparent difficulty for students in order to focus the educational research most effectively. Second, potential sources of these difficulties should be identified as early as possible in order to design appropriate research instruments. In the initial stages, one source of both types of baseline information is the high school physics teacher.

This is intended as a preliminary study to identify the most difficult concepts in the present physics curriculum and to suggest possible reasons for the difficulties.

II. Method

A. Design

A survey questionnaire was selected as the research instrument most compatible with the purpose of this study because data could be obtained fairly easily from a large cross-section of the physics teachers. In developing the survey, several important considerations were taken into account in the design and pilot-testing of the questionnaire.

First, the course content was described in terms of physical concepts rather than chapter headings in order to provide a list of concepts suitable for further educational research. This resulted in a list of concepts considerably longer than the simple chapter headings and thus introduced the possibility that the subjects would be fatigued by the length of the list. The fatigue factor effectively limited the length of the concept list. Furthermore, since the study was aimed at student difficulties with specific physical concepts, the data analysis procedures commonly used in physics (eg. graphing, significant figures, etc.) were excluded from the concept list. In the final version of the questionnaire, the Physics 11 course was described by 22 concepts while the Physics 12 course required 30 concepts.

The second major design consideration involved the scale for the easy/difficult rating. This was a 5-point scale with non-linear subdivisions involving the following categories:

- 1 - Easy for 90% of the students
- 2 - Easy for 75% of the students
- 3 - Easy for 50% and difficult for 50%
- 4 - Difficult for 75% of the students
- 5 - Difficult for 90% of the students
- NA - Not applicable

The non-linearity of the scale was introduced to avoid the collapse of a 5-point scale into a 3-point scale which probably would have occurred had the extreme scale values been referenced to 100%.

The third design consideration was the list of possible sources of difficulty which had to be comprehensive enough to include the most frequently cited reasons but not so extensive as to produce fatigue of the part of the subject. A list of 14 possible sources of difficulty was established and used for both the Physics 11 and Physics 12 questionnaires. This list included the following reasons:

- 1. Poor explanation in textbook
- 2. Lack of worked examples in textbook
- 3. Experimental instructions are confusing
- 4. Lack of mathematical skills
- 5. Pace of covering material is too rapid
- 6. Concept has little inherent interest to students
- 7. Vector nature of concept
- 8. Lack of transfer from experiment to problem-solving

9. Lack of relevant physical experience to relate to concept.
10. Failure to visualize the situation
11. Confusion from previous school learning
12. Confusion from previous non-school learning
13. Concept is too abstract
14. Other (please specify)

Given this list, the subjects were asked to select the reasons which they would link to the difficulties students experienced with particular physical concepts. Provision was made for selecting two reasons for each physical concept.

The original questionnaire was revised following a pilot study involving seven physics teachers from schools in the Lower Mainland. Revision consisted of clarification of the concept list and refinement of the list of possible sources of difficulty. In the pilot study, feedback was also obtained regarding the time required to complete the questionnaire.

B. Subjects

A decision to sample all physics teachers in the public schools of B.C. was made because the total number of physics teachers is less than 200. Teachers names and school addresses were provided by the B.C. Research Council after authorization to use the 1978/1979 Form J data had been obtained from the Ministry of Education. Using the B.C. Research Council sampling frame, teachers were randomly selected to receive either the Physics 11 or Physics 12 questionnaire on a probability basis weighted by their relative teaching load in each of the two subjects. In total there were 51 subjects in the Physics 12 sample group and 146 subjects in the Physics 11 sample group.

The questionnaires were mailed during the last week of May 1978 and included a return envelope which had been stamped and addressed. Since the return envelope contained the name of the teacher, a follow-up letter could be sent during the last week of June 1978 to those who had not responded to the initial mailing.

C. Data Analysis Procedures

Most of the data analysis was done at the University of British Columbia using the subprogram FREQUENCIES from the Statistical Package for the Social Sciences (SPSS) system. This subprogram provides descriptive statistics and includes such options as mean, mode, median, standard deviation, etc. Data is frequently missing in survey research and this questionnaire was certainly no exception as the number of responses varied for each concept. All calculations were performed using the actual number of responses rather than the possible number of responses. Following this, a second calculation was done to show the percentage response to each concept.

In the sources of difficulty section, the questionnaire allowed for the possibility of two responses to each concept. During the data analysis, the two reasons were collapsed using a 2 to 1 weighting between the first and second reasons. This information was then converted to a percentage response of the actual number of responses. An example from the Physics 11 questionnaire illustrates this procedure:

CONCEPT	SOURCES OF DIFFICULTY		
	Poor explanation in textbook	Lack of worked examples in text	Total number of responses
Determination of frequency using strobe	Reason 1 - 16	Reason 1 - 5	Reason 1 - 82
	Reason 2 - 8	Reason 2 - 19	Reason 2 - 66
	Weighted - 40	Weighted - 29	Weighted - 230
	Percent - 17.4%	Percent - 12.6%	Percent - 100%

The weighting of 2 to 1 between the first and second reasons is arbitrary and so the final data has no absolute referents and can only be used for inter-comparison purposes. In the tables included in this report, only the final percentage values are given.

III. Results

A. Physics 11 Results

For the Physics 11 survey, 93 responses were received from a total of 146 questionnaires to give a 64% return rate. In addition, 87% of those who responded added hand-written comments on the last page of the survey.

The percentage rate of response to the concepts in the Physics 11 curriculum is shown in Table 1. This table is included to show the "missing data" effect because all subsequent tables are normalized to 100%. The overall response rate is 71.7% with a standard deviation of 10.9%. It is obvious from this table that not all concepts received equal response from the subjects. What is not so obvious is the reason for the missing data. It may be that the concept has been effectively "dropped" from the curriculum. On the other hand, the teachers may not have a strong opinion regarding the reasons for a particular concept causing difficulty and would therefore not be inclined to provide data in that part of the questionnaire. It could

be argued that the missing data is a function of the questionnaire itself if the description of a concept lacks clarity and therefore leads to confusion on the part of the subject. Given the format and objectives of the survey, it is impossible to pinpoint specific reasons for the missing data.

TABLE 1: PERCENTAGE RESPONSE TO CONCEPTS IN PHYSICS 11

RESPONSE	CONCEPT
85.3	Determination of frequency using stroboscope
79.2	Measurement of distance using parallax method
79.2	Constant velocity motion
84.9	Constant acceleration motion
86.7	Projectile motion
81.0	Addition and subtraction of vectors
62.7	Vectors in three dimensions
78.9	Forces in static equilibrium
68.8	Torque and rotational equilibrium
68.8	Mass and weight
53.0	Analysis of spectra
43.7	Behaviour of gases
71.0	Reflection of light from plane mirrors
77.8	Reflection of light from curved mirrors
63.4	Reflection of water waves
77.1	Formation of images
77.1	Refraction of light
77.8	Behaviour of lenses
65.2	Refraction of water waves
70.6	Diffraction of light
60.9	Diffraction of water waves
63.4	Measurement of wavelength of light

The results of the EASY/DIFFICULT rating for the Physics 11 concepts are shown in Table 2. Most of the concepts receive a rating of less than 3.00 which indicates that teachers perceive these concepts to be easy for more than 50% of their students.

TABLE2: EASY/DIFFICULT RATING FOR PHYSICS 11 CONCEPTS	
RESPONSE	CONCEPT
2.60	Determination of frequency using strobe
2.61	Measurement of distance using parallax
2.03	Constant velocity motion
2.90	Constant acceleration motion
3.58	Projectile motion
2.67	Addition and subtraction of vectors
3.89	Vectors in three dimensions
2.87	Forces in static equilibrium
2.91	Torque and rotational equilibrium
2.33	Mass and weight
2.37	Analysis of spectra
2.81	Behaviour of gases
1.55	Reflection of light from plane mirrors
2.27	Reflection of light from curved mirrors
2.28	Reflection of water waves
2.45	Formation of images
2.39	Refraction of light
2.51	Behaviour of lenses
2.90	Refraction of water waves
3.33	Diffraction of light
3.10	Diffraction of water waves
3.23	Measurement of wavelength of light

The concepts which received a rating greater than 3.00 are:

- 3.58 - projectile motion
- 3.89 - three dimensional vectors
- 3.33 - diffraction of light
- 3.10 - diffraction of water waves
- 3.23 - measurement of the wavelength of light

In this group of the 5 most difficult concepts in the Physics 11 curriculum, only 'projectile motion' received a higher than average response. (see Table 1) In fact, at 86.7%, 'projectile motion' had the highest response of all the Physics 11 concepts. It seems that difficulty alone is not a sufficient criterion for a concept being "dropped" from the curriculum. If it were, then 'projectile motion' would most certainly be excluded from the Physics 11 curriculum since it has the second highest difficulty rating.

Data from the second part of the questionnaire, POSSIBLE SOURCES OF DIFFICULTY, is given in Table 3. Considering the reasons given for the five most difficult concepts reveals that:

1. projectile motion - 'vector nature of the concept' and 'lack of mathematical skills' account for almost 45% of the perceived difficulties
2. three dimensional vectors - 'failure to visualize the situation', 'lack of mathematical skills', and abstract level of the concept' account for about 55% of the perceived difficulty
3. diffraction of light - 'the textbook' and 'abstract nature of the concept' account for 35% of the perceived difficulty but no single factor clearly dominates the list
4. diffraction of water waves - no single factor dominates but 'lack of physical experience' receives its highest ranking for this concept
5. measurement of the wavelength of light - no single factor dominates but 'rapid pace' receives its highest ranking for this concept.

Integrating over all physical concepts, the five most frequently cited sources of difficulty are:

- 15.4% - Poor explanation in textbook
- 15.2% - Lack of worked examples in textbook
- 12.9% - Lack of mathematical skills
- 12.6% - Failure to visualize the situation
- 9.0% - Experimental instructions confusing

From the teachers' point of view, these five factors account for 65% of the sources of difficulty with concepts in the Physics 11 curriculum.

TABLE 3: SOURCES OF DIFFICULTY FOR CONCEPTS IN PHYSICS 11

CONCEPT	SOURCES OF DIFFICULTY													
	Poor explanation in textbook	Lack of worked examples in text	Experimental instructions confusing	Lack of mathematical skills	Pace of covering material is too rapid	Concept has little inherent interest to students	Vector nature of concept	Lack of transfer from experiment to problem-solving	Lack of relevant physical experience to relate to concept	Failure to visualize the situation	Confusion from previous school-learning	Confusion from previous non-school learning	Concept is too abstract	Other
Determination of frequency using strobe	17.4	12.6	11.3	7.4	3.9	6.1	0	4.3	7.4	17.4	0	0	0	12.2
Determination of distance using parallax	20.8	11.1	13.0	17.6	1.9	4.2	0	4.6	6.0	16.6	0	.5	1.9	1.9
Motion with constant velocity	14.8	10.7	9.4	25.1	1.5	3.0	3.4	3.4	1.0	7.9	2.0	3.4	3.9	2.5
Motion with constant acceleration	13.8	13.8	11.6	27.2	2.2	1.8	3.1	2.2	3.1	9.8	0	3.6	5.4	2.2
Projectile motion	14.1	11.1	4.3	18.8	3.8	1.3	25.6	3.8	3.4	8.1	0	.9	3.0	1.7
Addition and subtraction of vectors	17.2	13.4	1.4	24.4	3.3	1.9	9.6	1.9	7.7	12.4	0	0	4.8	1.0
Three-dimensional vectors	8.5	11.1	2.1	17.0	5.3	5.3	4.8	.5	5.3	27.1	0	0	11.7	1.1
Forces in static equilibrium	14.0	13.5	6.0	18.6	4.2	3.7	15.8	5.1	2.8	11.6	0	0	.9	1.7

CONCEPT	SOURCES OF DIFFICULTY													
	Poor explanation in textbook	Lack of worked examples in text	Experimental instructions confusing	Lack of mathematical skills	Pace of covering material is too rapid	Concept has little inherent interest to student	Vector nature of concept	Lack of transfer from experiment to problem-solving	Lack of relevant physical experience to relate to concept	Failure to visualize the situation	Confusion from previous school learning	Confusion from previous non-school learning	Concept is too abstract	Other
Torque	17.7	21.0	3.3	16.0	4.4	3.3	3.3	6.6	7.2	11.6	.6	.6	1.1	3.3
Mass and Weight	22.9	10.6	2.9	2.4	4.1	3.5	0	1.8	8.8	9.4	12.9	9.4	10.0	1.2
Analysis of spectra	26.8	12.3	10.9	2.9	7.2	5.1	.7	.7	12.3	5.8	2.9	0	6.5	5.8
Gases	20.5	11.8	7.9	8.7	11.0	8.7	.8	4.7	8.7	10.2	2.4	0	1.6	3.1
Reflection of light from plane mirror	18.8	12.4	14.7	2.9	7.1	5.9	0	9.4	.6	16.5	3.5	5.3	.6	2.4
Reflection of light from curved mirror	14.1	15.1	15.1	10.1	5.5	4.0	0	13.6	4.5	11.6	.5	2.0	2.0	2.0
Reflection of water waves	17.9	11.0	21.2	3.3	5.3	11.3	0	9.3	2.6	14.6	0	1.3	0	1.3
Formation of images	18.2	11.1	13.6	8.1	3.5	3.0	0	9.1	5.1	19.2	2.0	2.0	4.5	1.0
Refraction of light	15.2	13.2	13.7	16.2	5.1	2.5	0	11.7	2.5	10.2	2.0	2.0	3.0	2.5

CONCEPT	SOURCES OF DIFFICULTY													
	Poor explanation in textbook	Lack of worked examples in text	Experimental instructions confusing	Lack of mathematical skills	Pace of covering material is too rapid	Concept has little inherent interest to students	Vector nature of concept	Lack of transfer from experiment to problem-solving	Lack of relevant physical experience to relate to concept	Failure to visualize the situation	Confusion from previous school-learning	Confusion from previous non-school learning	Concept is too abstract	Other
Behaviour of lenses	14.0	14.5	10.5	12.5	6.0	4.5	0	15.0	3.0	14.5	1.0	0	3.5	1.0
Refraction of water waves	16.1	6.5	15.5	6.0	6.5	6.5	0	8.3	13.7	11.9	.6	0	4.2	4.2
Diffraction of light	20.1	4	8.2	9.2	9.2	3.8	0	4.9	10.3	10.3	0	0	15.8	2.7
Diffraction of water waves	16.0	8.3	12.8	4.5	9.0	3.8	0	6.4	12.8	8.3	0	1.3	9.6	7.1
Measurement of wavelength of light	14.9	8.3	11.3	10.7	13.1	3.6	0	7.1	4.2	10.7	0	0	9.5	6.5
PERCENTAGE OF TOTAL RESPONSE	15.4	15.2	9.0	12.9	5.1	4.6	3.4	6.3	5.9	12.6	1.2	1.4	4.2	2.9

B. Physics 12 Results

Of the 51 questionnaires mailed to Physics 12 teachers, 37 were completed and returned to yield a response rate of 73%.

The percentage rate of response to the concepts in the Physics 12 curriculum is shown in Table 4. The overall response rate was 77.7% with a standard deviation of 4.7%. In comparison to the Physics 11 response rate, the average is higher by 6% and shows 6% less deviation.

TABLE 4: PERCENTAGE RESPONSE TO CONCEPTS IN PHYSICS 12

RESPONSE	CONCEPT
84.7	Newton's laws of motion
83.8	Projectile motion
84.7	Circular motion
85.6	Simple harmonic motion
76.6	Universal Law of Gravitation
80.2	Satellite motion
76.6	Straight line momentum interactions
84.7	Oblique momentum interactions
74.8	Center of mass reference frame
73.9	Work
74.8	Kinetic energy
81.1	Spring potential energy
80.2	Gravitational potential energy
74.8	Conservation of energy
75.7	Coulomb's Law of electric force
78.4	Electric field strength
73.0	Electric field patterns
84.7	Electric potential energy
82.9	Electric potential difference
70.3	Motion of ions in solution
73.0	Resistance
75.7	Capacitance
75.7	Strength of magnetic field
78.4	Motion of charge in magnetic field
82.0	Induced EMF
76.6	Motor
70.3	Rutherford scattering experiment
72.1	Hydrogen spectrum
73.0	Photoelectric effect
73.0	Properties of the photon

The results of the EASY/DIFFICULT RATING are given in Table 5. In the Physics 12 curriculum 7 of the 30 concepts were rated greater than 3.00 which means that they were perceived by the teachers as being difficult for more than half of the students.

TABLE 5: EASY/DIFFICULT RATING FOR PHYSICS 12 CONCEPTS

RATING	CONCEPT
2.05	Newton's laws of motion
2.62	Projectile motion
2.92	Circular motion
3.30 **	Simple harmonic motion
2.16	Universal Law of Gravitation
2.86	Satellite motion
1.97	Straight line momentum interactions
3.16 **	Oblique momentum interactions
3.87 **	Center of mass reference frame
1.89	Work
2.00	Kinetic energy
2.83	Spring potential energy
2.89	Gravitational potential energy
2.16	Conservation of energy
1.97	Coulomb's Law of electric force
2.51	Electric field strength
2.00	Electric field patterns
3.11 **	Electric potential energy
3.03 **	Electric potential difference
2.19	Motion of ions in solution
1.87	Resistance
2.61	Capacitance
2.82	Strength of magnetic field
2.86	Motion of charge in magnetic field
3.31 **	Induced EMF
2.91	Motor
3.19 **	Rutherford scattering experiment
2.94	Hydrogen spectrum
2.52	Photoelectric effect
2.97	Properties of the photon

Of the seven most difficult concepts, three are from the mechanics section, three from the electromagnetic section, and one from the modern physics section.

Data from the second part of the Physics 12 questionnaire, POSSIBLE SOURCE OF DIFFICULTY, is given in Table 6. Considering the concepts which received a rating greater than 3.00 reveals that:

1. simple harmonic motion - 'the textbook', 'lack of worked examples', and 'lack of mathematical skills' account for more than 50% of the perceived difficulty.
2. oblique momentum interactions - 'vector nature of the concept' accounts for 37% of the perceived difficulty. This is the highest percentage attributed to a single cause in either of the two questionnaires.

3. Center of mass reference frame - 'failure to visualize the situation' and 'concept too abstract' are the two reasons most frequently cited and account for almost 45% of the response.
4. Electric potential energy- the most important reason given here is 'concept is too abstract'. This reason alone accounts for 25% of the response while 'the textbook' and 'failure to visualize the situation' account for another 35% of the response.
5. electric potential difference - once again, the reason 'concept is too abstract' accounts for 25% of the response.
6. Induced EMF - the two reasons which account for 35% of the response are 'concept is too abstract' and 'failure to visualize the situation'.
7. Rutherford scattering experiment - once again, 'concept is too abstract' and 'failure to visualize the situation' account for 35% of the response. In this case, 'the textbook' rivals 'concept is too abstract' as an important factor. 'Pace of covering material is too rapid' also emerges as an important factor. These four factors account for 65% of the response to this concept.

Integrating over all of the 30 concepts listed for the Physics 12 curriculum, reveals that the five most frequently chosen sources of difficulty are:

- 19.2% - lack of worked examples
- 17.1% - poor explanation in textbook
- 12.6% - failure to visualize the situation
- 9.4% - concept is too abstract
- 8.0% - lack of mathematical skills

These five factors alone account for 65% of the perceived difficulties with the Physics 12 curriculum. It is interesting to note that four of the five factors also appear as the primary sources of difficulty for the Physics 11 curriculum, and that the Physics 12 curriculum is perceived as more abstract than the Physics 11 curriculum. Furthermore, it is the abstract nature of the concepts which is often linked to the most difficult concepts.

TABLE 6: SOURCES OF DIFFICULTY FOR CONCEPTS IN PHYSICS 12

SOURCES OF DIFFICULTY

CONCEPT	Poor explanation in textbook	Lack of worked examples in text	Experimental instructions confusing	Lack of mathematical skills	Pace of covering material is too rapid	Concept has little inherent interest to students	Vector nature of concept	Lack of transfer from experiment to problem-solving	Lack of relevant physical experience to relate to concept	Failure to visualize the situation	Confusion from previous school-learning	Confusion from previous non-school learning	Concept is too abstract	Other
Newton's laws of motion	18.2	23.9	9.1	10.2	9.1	0	5.7	5.7	2.3	6.8	2.3	0	3.4	3.4
Projectile motion	14.9	24.1	1.1	10.3	5.7	1.1	27.6	0	2.3	8.0	2.3	0	1.1	1.1
Circular motion	10.2	15.9	3.4	9.1	8.0	1.1	21.6	6.8	3.4	10.2	2.3	3.4	3.4	1.1
Simple harmonic motion	20.2	15.7	4.5	15.7	7.9	1.1	6.7	2.2	3.4	14.6	0	0	6.7	1.1
Universal Law of Gravitation	13.0	20.8	2.6	11.7	5.2	2.6	0	1.3	11.7	18.2	1.3	0	7.8	3.9
Satellite motion	22.6	23.8	1.2	15.5	7.1	0	7.1	3.6	4.8	10.7	0	0	2.4	1.2
Straight line momentum interactions	14.5	23.7	9.2	15.8	3.9	1.3	5.3	11.8	0	5.3	0	0	2.6	6.6
Oblique momentum interactions	13.5	15.7	1.1	12.4	4.5	0	37.1	2.2	1.1	4.5	0	0	2.2	5.6
Center of mass reference frame	19.8	6.2	1.2	4.9	6.2	8.6	2.5	0	4.9	23.5	0	0	21.0	1.2

CONCEPT	SOURCES OF DIFFICULTY													
	Poor explanation in textbook	Lack of worked examples in text	Experimental instructions confusing	Lack of mathematical skills	Pace of covering material is too rapid	Concept has little inherent interest to students	Vector nature of concept	Lack of transfer from experiment to problem-solving	Lack of relevant physical experience to relate to concept	Failure to visualize the situation	Confusion from previous school-learning	Confusion from previous non-school learning	Concept is too abstract	Other
Work	18.3	26.8	1.4	2.8	5.6	0	0	7.0	5.6	9.9	2.8	7.0	11.3	1.4
Kinetic energy	16.4	30.1	2.7	8.2	8.2	4.1	0	5.5	0	12.3	0	2.7	8.2	1.4
Spring potential energy	20.7	15.9	7.3	7.3	6.1	2.4	1.2	6.1	2.4	13.4	0	0	13.4	3.7
Gravitational potential energy	22.5	11.3	3.8	5.0	5.0	0	2.5	6.3	3.8	12.5	0	2.5	21.3	3.8
Conservation of energy	18.6	20.0	4.3	8.6	5.7	5.7	0	8.6	2.9	14.3	0	2.9	7.1	1.4
Coulomb's Law of electric force	11.8	25.0	3.9	13.2	3.9	2.6	2.6	2.6	11.8	10.5	0	0	5.3	6.6
Electric field strength	18.2	27.3	2.6	1.3	5.2	0	2.6	5.2	6.5	11.7	3.9	0	11.7	3.9
Electric field patterns	28.2	13.0	2.8	1.4	7.0	7.0	1.4	0	4.2	16.9	2.8	0	12.7	1.4
Electric potential energy	19.1	13.5	1.1	5.6	5.6	2.2	0	2.2	3.4	16.9	0	2.2	24.7	3.4

CONCEPT	SOURCES OF DIFFICULTY													
	Poor explanation in textbook	Lack of worked examples in text	Experimental instructions confusing	Lack of mathematical skills	Pace of covering material is too rapid	Concept has little inherent interest to students	Vector nature of concept	Lack of transfer from experiment to problem-solving	Lack of relevant physical experience to relate to concept	Failure to visualize the situation	Confusion from previous school-learning	Confusion from previous non-school learning	Concept is too abstract	Other
Electric potential difference	22.1	15.1	1.2	4.7	5.8	0	0	0	2.3	12.8	4.7	2.3	25.6	2.5
Motion of ions in solution	22.7	21.2	1.5	4.5	6.1	7.6	0	3.0	0	12.1	10.6	3.0	3.0	4.5
Resistance	19.4	29.9	1.5	4.5	4.5	0	0	1.5	9.0	11.9	10.4	3.0	3.0	1.5
Capacitance	22.7	22.7	4.0	1.3	5.3	2.7	0	5.3	8.0	14.7	5.3	1.3	2.7	4.0
Strength of magnetic field	22.8	16.5	1.3	2.5	5.3	0	7.6	1.3	7.6	16.5	3.8	2.5	5.3	5.1
Motion of charge in magnetic field	21.5	11.3	3.8	6.3	3.8	0	12.7	1.3	5.3	17.7	0	0	10.1	5.1
Induced EMF	16.5	10.6	7.1	3.5	8.2	2.4	3.5	1.2	8.2	16.5	0	0	18.8	3.5
Motor	25.0	12.5	7.1	2.5	11.3	2.5	0	3.8	5.0	13.8	3.8	2.5	6.3	3.8

CONCEPT	SOURCES OF DIFFICULTY													
	Poor explanation in textbook	Lack of worked examples in text	Experimental instructions confusing	Lack of mathematical skills	Pace of covering material is too rapid	Concept has little inherent interest to students	Vector nature of concept	Lack of transfer from experiment to problem-solving	Lack of relevant physical experience to relate to concept	Failure to visualize the situation	Confusion from previous school-learning	Confusion from previous non-school learning	Concept is too abstract	Other
Rutherford scattering experiment	17.8	6.8	5.5	6.8	13.7	5.5	0	0	2.7	16.4	0	0	17.8	6.8
Hydrogen spectrum	19.7	13.2	3.9	2.6	18.4	3.9	0	0	5.3	11.8	0	0	17.1	3.9
Photoelectric effect	20.0	13.3	2.7	2.7	16.0	0	0	1.3	10.7	13.3	0	0	13.3	6.7
Properties of the photon	18.7	6.7	1.3	1.3	16.0	0	0	0	12.0	10.7	2.7	0	26.7	4.0
PERCENTAGE OF TOTAL RESPONSE	17.1	19.2	4.2	8.0	7.8	2.0	4.9	3.2	4.9	12.6	1.7	1.1	9.4	3.8

IV. Discussion

This study was undertaken on the assumption that differences exist in the difficulty level of various physical concepts and that information available from physics teachers would permit the ordering of these concepts according to difficulty level. In so far as the data reveals difficulty levels varying from a low of 1.55 to a high of 3.89, it supports the initial assumption. The discussion of the most difficult concepts has been referenced to a value of 3.00 which had been defined as "easy for 50% of the students and difficult for 50% of the students." However, the choice of 3.00 as a reference point raises some significant questions.

First, one might consider the value of the difficulty rating which would be desirable. It is not obvious that one should choose 3.00 as the acceptable value but it is apparent that a value which is too low could tend to lead to boredom while a value which is too high could lead to intolerable levels of student frustration.

Second, one might consider whether the curriculum should be homogeneously difficult; that is, that all concepts should receive the same difficulty rating within some uncertainty limit. For example, would it be desirable that all concepts receive a rating of $2.70 \pm .20$? Or, from another viewpoint, are variations in difficulty level desirable and, if so, how much variation should exist?

Third, one might consider whether the average rating of all Physics 12 concepts (which was $2.65 \pm .52$) should be different from the average rating of all Physics 11 concepts. ($2.71 \pm .52$) If so, should it be higher or lower?

Of course, the natural variations in classes from year to year may be much greater than the effects considered by these questions and therefore lead one to ignore the questions, or, to conclude that they are of purely academic interest. However, the small increase in enrollment in physics and the reputation of the physics course for being difficult both point toward exactly the opposite conclusion. That is, the effect of the difficulty of the concepts is a stronger influence than the effect of the variation in students from class to class and from year to year.

None of these questions was specifically addressed in this study but from the point of view of curriculum development, the usefulness of the data depends on answers to questions such as these. For the classroom teacher, the data can serve to draw attention to parts of the curriculum which should be handled with extra care because of their potential for difficulty. For the educational researcher, the data points to concepts worthy of additional detailed study and permits the selection of these concepts on the basis of perceived needs. For example, the cluster of concepts related to various types of motion form a significant part of the curriculum and appear to increase in level of difficulty. In the Physics 11 curriculum, 'projectile motion' (3.58) emerges as one of the most difficult concepts. It reappears in the Physics 12 curriculum at a lower difficulty rating (2.62) but is united with circular motion (2.92) and simple harmonic motion (3.30) in a unit of increasing difficulty. Either individually, or in a cluster, these concepts are an important area for further educational research.

In asking teachers to select POSSIBLE SOURCES OF DIFFICULTY for each physical concept, the implicit assumption is that there are different reasons for students encountering difficulty with concepts such as 'projectile motion' or 'refraction of water waves'. In fact, 80% of those who completed the questionnaire were able to give differentiated responses. The list of fourteen POSSIBLE SOURCES OF DIFFICULTY includes four subgroups which, though neither unique nor mutually exclusive, provide further insight into the trends in the data. These four subgroups are:

1. Reasons related to the text materials
 - poor explanation in textbook
 - lack of worked examples in text
 - experimental instructions confusing
2. Reasons related to the properties of the physical concept
 - concept has little inherent interest to students
 - vector nature of concept
 - concept is too abstract
3. Reason related to the background preparation of the student
 - lack of mathematical skills
 - lack of relevant physical experience to relate to concept
 - confusion from previous school learning
 - confusion from previous non-school learning
4. Reasons related to the ability level of the student
 - pace of covering material is too rapid
 - lack of transfer from experiment to problem solving
 - failure to visualize the situation

By adding results for all of the reasons in each subgroup, the following percentages are obtained:

TYPE OF REASON	PERCENTAGE OF RESPONSE	
	Physics 11	Physics 12
Text materials	40.0%	40.5%
Properties of concept	12.2%	16.3%
Background preparation of the student	21.4%	15.6%
Ability level of the student	24.0%	23.6%
TOTAL	97.6%	96.0

The importance of the textbook and its perceived relationship to student difficulties cannot be ignored. As this is one factor over which some control can be exercised, it is imperative that the effect of the textbook as a source of difficulty should be minimized. A readability study of the prescribed textbooks in the B.C. curriculum (Bruinsma, 1978) indicates that the P.S.S.C text is at the grade 12 reading level. Attention to this single factor could contribute a great deal toward the reduction of difficulty of the physics curriculum.

The dominance of the text materials as a source of difficulty could tend to obscure other important factors by giving the teacher a readily available "scapegoat" to explain why students have difficulty with physics. In the long run, this serves to reduce the teacher's effectiveness for two reasons. First, having an answer usually means that one need not consider other possibilities and the teacher could become desensitized to other considerations. Second, the work involved in compensating for the perceived weaknesses in the text materials (providing notes, worksheets, etc) leaves the teacher with less time and energy for interaction with the students who, after all, are the ones most able to articulate their problems. Without direct input from the student, the teacher has no reason to change his opinion that the text is the source of most of the student difficulty. Thus, the role of the textbook is central to both the sources of difficulty and to the teacher's ability to perceive the sources of difficulty.

Reasons related to the ability level of the student emerge as the second most important source of difficulty and account for 24% of the response. In this group, the students' 'failure to visualize the situation' is the dominant factor and suggests the need for research aimed at understanding the roots of this 'failure'. In general, the characteristics of the student (ability level, background preparation) are considered to be more important than the characteristics of the physical concepts in identifying sources of difficulty. Of course, this is from the teachers' viewpoint and another study could be done to determine student response to the same questionnaire. Correlations between student and teacher response might prove illuminating.

Other correlation studies are possible using the data already collected. For example, the questionnaire included questions related to class size, teaching load, background experience, etc. Correlation studies between "years of physics teaching experience" and "average difficulty rating" are possible using the present data but, since these questions were not part of the mandate of the original study, they have not been pursued.

As stated in the introduction, this study was intended as a preliminary step aimed at acquiring baseline data and a rough "map of the territory". As with most research, it has yielded more questions than answers.

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PHYSICS 11 — Concept Evaluation

A. GENERAL INFORMATION

1. Years of teaching experience as of June 1979:

- a) 1 or less ☐
- b) 2-5 ☐
- c) 6-9 ☐
- d) 10-13 ☐
- e) 14 or more ☐

2. Years of physics teaching experience as of June 1979:

- a) 1 or less ☐
- b) 2-5 ☐
- c) 6-9 ☐
- d) 10-13 ☐
- e) 14 or more ☐

3. What is your average class size in physics 11?

- a) 1-10 ☐
- b) 11-15 ☐
- c) 16-20 ☐
- d) 21-25 ☐
- e) 26 or more ☐

4. What percentage of your teaching assignment is represented by physics 11?

- a) 0-25% ☐
- b) 26-50% ☐
- c) 51-75% ☐
- d) 76-100% ☐

5. What university degrees(s) have you obtained?

6. What major(s) do you have?

B. EASY/DIFFICULT RATING

For each of the following concepts from the Physics 11 curriculum, please circle the appropriate number on the scale to indicate the apparent difficulty of that concept for your students. The scale includes a not applicable category which can be used if you do not teach the concept. If this is the case, please explain why the concept is not taught.

1	2	3	4	5	NA
Easy for 90% of the students.	Easy for 75% of the students.	Easy for 50% and difficult for 50%.	Difficult for 75% of the students.	Difficult for 90% of the students.	Not applicable.

Determination of frequency using stroboscope	1	2	3	4	5	NA
Measurement of distance using parallax method	1	2	3	4	5	NA
Constant velocity motion	1	2	3	4	5	NA
Constant acceleration motion	1	2	3	4	5	NA
Projectile motion	1	2	3	4	5	NA
Addition and subtraction of vectors	1	2	3	4	5	NA
Vectors in three dimensions	1	2	3	4	5	NA
Forces in static equilibrium	1	2	3	4	5	NA
Torque and rotational equilibrium	1	2	3	4	5	NA
Mass and weight	1	2	3	4	5	NA
Analysis of spectra	1	2	3	4	5	NA
Behaviour of gases	1	2	3	4	5	NA
Reflection of light from plane mirrors	1	2	3	4	5	NA
Reflection of light from curved mirrors	1	2	3	4	5	NA
Reflection of water waves	1	2	3	4	5	NA
Formation of images	1	2	3	4	5	NA
Refraction of light	1	2	3	4	5	NA
Behaviour of lenses	1	2	3	4	5	NA
Refraction of water waves	1	2	3	4	5	NA
Diffraction of light	1	2	3	4	5	NA
Diffraction of water waves	1	2	3	4	5	NA
Measurement of wavelength of light	1	2	3	4	5	NA

C. SOURCES OF DIFFICULTY

Below is a list of possible reasons why students have trouble with different concept within the physics curriculum.

The purpose of this section of the questionnaire is to provide a detailed description of the curriculum and identify the sources of difficulty concept-by-concept. It may take some time to complete this section, but please do not give up!

THE POSSIBLE REASONS:

1. Poor explanation in textbook.
2. Lack of worked examples in textbook.
3. Experimental instructions are confusing.
4. Lack of mathematical skills.
5. Pace of covering material is too rapid.
6. Concept has little inherent interest to students.
7. Vector nature of concept.
8. Lack of transfer from experiment to problem-solving.
9. Lack of relevant physical experience to relate to concept.
10. Failure to visualize the situation.
11. Confusion from previous school learning.
12. Confusion from previous non-school learning.
13. Concept is too abstract.
14. Other (please specify).

From the list on the preceeding page, please select the reason (or reasons) which you consider most important in identifying why students have difficulty with each concept.

	Most Important Reason	Second Reason
Determination of frequency using stroboscope	☐	☐
Measurement of distance using parallax method	☐	☐
Constant velocity motion	☐	☐
Constant acceleration motion	☐	☐
Projectile motion	☐	☐
Addition and subtraction of vectors	☐	☐
Vectors in three dimensions	☐	☐
Forces in static equilibrium	☐	☐
Torque and rotational equilibrium	☐	☐
Mass and weight	☐	☐
Analysis of spectra	☐	☐
Behaviour of gases	☐	☐
Reflection of light from plane mirrors	☐	☐
Reflection of light from curved mirrors	☐	☐
Reflection of water waves	☐	☐
Formation of images	☐	☐
Refraction of light	☐	☐
Behaviour of lenses	☐	☐
Refraction of water waves	☐	☐
Diffraction of light	☐	☐
Diffraction of water waves	☐	☐
Measurement of wavelength of light	☐	☐

D. ADDITIONAL COMMENTS

I would appreciate any additional comments which might clarify the reasons for the difficulty which students experience with physics.

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PHYSICS 12 — Concept Evaluation

A. GENERAL INFORMATION

1. Years of teaching experience as of June 1979:

- a) 1 or less ☐
- b) 2-5 ☐
- c) 6-9 ☐
- d) 10-13 ☐
- e) 14 or more ☐

2. Years of physics teaching experience as of June 1979:

- a) 1 or less ☐
- b) 2-5 ☐
- c) 6-9 ☐
- d) 10-13 ☐
- e) 14 or more ☐

3. What is your average class size in physics 12?

- a) 1-10 ☐
- b) 11-15 ☐
- c) 16-20 ☐
- d) 21-25 ☐
- e) 26 or more ☐

4. What percentage of your teaching assignment is represented by physics 12?

- a) 0-25% ☐
- b) 26-50% ☐
- c) 51-75% ☐
- d) 76-100% ☐

5. What university degree(s) have you obtained?

6. What major(s) do you have?

B. EASY/DIFFICULT RATING

For each of the following concepts from the Physics 12 curriculum, please circle the appropriate number on the scale to indicate the apparent difficulty of that concept for your students. The scale includes a not applicable category which can be used if you do not teach the concept. If this is the case, please explain why the concept is not taught.

1	2	3	4	5	NA
Easy for 90% of the students.	Easy for 75% of the students.	Easy for 50% and difficult for 50%.	Difficult for 75% of the students.	Difficult for 90% of the students.	Not applicable.

Newton's Laws of motion	1	2	3	4	5	NA
Projectile motion	1	2	3	4	5	NA
Circular motion	1	2	3	4	5	NA
Simple harmonic motion	1	2	3	4	5	NA
Universal Law of Gravitation	1	2	3	4	5	NA
Satellite motion	1	2	3	4	5	NA
Straight line momentum interactions	1	2	3	4	5	NA
Oblique momentum interactions	1	2	3	4	5	NA
Center of mass reference frame	1	2	3	4	5	NA
Work	1	2	3	4	5	NA
Kinetic energy	1	2	3	4	5	NA
Spring potential energy	1	2	3	4	5	NA
Gravitational potential energy	1	2	3	4	5	NA
Conservation of energy	1	2	3	4	5	NA
Coulomb's Law of electric force	1	2	3	4	5	NA
Electric field strength	1	2	3	4	5	NA
Electric field patterns	1	2	3	4	5	NA
Electric potential energy	1	2	3	4	5	NA
Electric potential difference	1	2	3	4	5	NA
Motion of ions in solution	1	2	3	4	5	NA
Resistance	1	2	3	4	5	NA
Capacitance	1	2	3	4	5	NA
Strength of magnetic field	1	2	3	4	5	NA
Motion of charge in magnetic field	1	2	3	4	5	NA
Induced EMF	1	2	3	4	5	NA
Motor	1	2	3	4	5	NA
Rutherford scattering experiment	1	2	3	4	5	NA
Hydrogen spectrum	1	2	3	4	5	NA
Photoelectric effect	1	2	3	4	5	NA
Properties of the photon	1	2	3	4	5	NA

C. SOURCES OF DIFFICULTY

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The purpose of this section of the questionnaire is to provide a detailed description of the curriculum and identify the sources of difficulty concept-by-concept. It may take some time to complete this section, but please do not give up!

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7. Vector nature of concept.
8. Lack of transfer from experiment to problem-solving.
9. Lack of relevant physical experience to relate to concept.
10. Failure to visualize the situation.
11. Confusion from previous school learning.
12. Confusion from previous non-school learning.
13. Concept is too abstract.
14. Other (please specify).

From the list on the preceeding page, please select the reason (or reasons) which you consider most important in identifying why students have difficulty with each concept.

	Most Important Reason	Second Reason
Newton's laws of motion	☐	☐
Projectile motion	☐	☐
Circular motion	☐	☐
Simple harmonic motion	☐	☐
Universal Law of Gravitation	☐	☐
Satellite motion	☐	☐
Straight line momentum interactions	☐	☐
Oblique momentum interactions	☐	☐
Center of mass reference frame	☐	☐
Work	☐	☐
Kinetic energy	☐	☐
Spring potential energy	☐	☐
Gravitational potential energy	☐	☐
Conservation of energy	☐	☐
Coulomb's Law of electric force	☐	☐
Electric field strength	☐	☐
Electric field patterns	☐	☐
Electric potential energy	☐	☐
Electric potential difference	☐	☐
Motion of ions in solution	☐	☐
Resistance	☐	☐
Capacitance	☐	☐
Strength of magnetic field	☐	☐
Motion of charge in magnetic field	☐	☐
Induced EMF	☐	☐
Motor	☐	☐
Rutherford scattering experiment	☐	☐
Hydrogen spectrum	☐	☐
Photoelectric effect	☐	☐
Properties of the photon	☐	☐

I would appreciate any additional comments which might clarify the reasons for the difficulty which students experience with physics.

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